

Longan Quality after Hot-water Immersion and X-ray Irradiation Quarantine Treatments

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Abstract. Hot-water immersion and irradiation quarantine treatments are used to disinfest longan [*Dimocarpus longan* (Lour.) Steud.] of fruit flies and other pests before export from Hawaii to the U.S. mainland. One day after harvest, longan fruit (cvs. Chompoo and Biew Kiew) were subjected to hot-water immersion at 49 °C for 20 minutes, irradiation treatment at a minimum absorbed dose of 400 Gy, or left untreated as controls. Fruit were then stored at 10 °C in perforated plastic bags, and quality attributes were evaluated after 7, 14, and 21 days. ‘Chompoo’ and ‘Biew Kiew’ fruit treated by hot-water immersion were darker (lower L*) and less intensely colored (lower C*) than irradiated or untreated fruits after 14 days of posttreatment storage. For both cultivars, external appearance of fruit treated by hot-water immersion was rated as unacceptable after 14 and 21 days of posttreatment storage, whereas irradiated and nontreated fruit were rated as acceptable on all days. *Penicillium* mold contributed to the unacceptable external appearance ratings after 21 days for fruit that were treated by hot-water immersion. With both cultivars, taste of fruit treated with hot-water immersion was rated as unacceptable after 21 days of storage, whereas irradiated fruit remained acceptable. Overall, under these experimental conditions, irradiation was superior to hot-water immersion as a quarantine treatment based upon the maintenance of fruit quality.

Longan (syn. lungan, longyen, langnan, lamyai pa, lengkeng, nhan, and “dragon’s eye”) is a subtropical evergreen tree-fruit native to northeastern India, Burma, and southern China (Watson, 1984; Zee et al., 1998). This species is closely related to lychee (*Litchi chinensis* Sonn.) in the family Sapindaceae, and both are grown in similar areas in China and Thailand, although climactic requirements differ slightly (Morton, 1987; Nakasone and Paull, 1998). Longan is a nonclimacteric fruit with a thin, green-brown, pliable pericarp and a translucent white edible aril (the “skin” and “flesh,” respectively) surrounding a single seed (Paull and Chen, 1987). In Hawaii, longan is one of the main crops of the rapidly expanding tropical specialty fruit industry.

There is substantial commercial interest in exporting fresh longans to the U.S. mainland

from Hawaii, and ‘Chompoo’ and ‘Biew Kiew’ are the major cultivars. Longans, like many other tropical fruits grown in Hawaii, are under a federal quarantine because the fruit is a potential host of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), and the oriental fruit fly, *Bactrocera dorsalis* Hendel. These pests are not established in the continental United States, and commodity quarantine treatments ensure that the risk of exporting them from Hawaii is minimized (Follett and Sanxter, 2000).

Two quarantine treatments have been developed for exporting longans from Hawaii to the U.S. mainland. Irradiation with a minimum absorbed dose of 250 Gy is a U.S. Dept. of Agriculture, Animal Plant Health Inspection Service (USDA–APHIS)-approved treatment for disinfestation of fruit flies in longan (Federal Register, 1998). Since 1995, various tropical fruits, including longan, have been flown from Hawaii to the U.S. mainland for irradiation treatment and subsequent distribution and sale. This practice is expensive because of the limited number of treatment facilities and their distances from major markets. An e-beam/converted X-ray facility has recently been constructed in Hawaii, and other irradiation facilities may be forthcoming if market interests grow. Irradiation with a minimum absorbed dose of 400 Gy is accepted by the California Dept. of Food and Agriculture (CDFA) for the treatment of insects other than fruit flies, and the commercial irradiation facility in Hawaii typically treats all tropical fruits at this level to avoid rejections due to the presence of non-fruit fly quarantine pests. A hot-water immersion treatment of 49 °C for 20

min, a USDA–APHIS-approved treatment for lychee from Hawaii (Federal Register, 1997), has been proposed for longan also (Follett unpublished), and is in the final stages of approval by USDA–APHIS. Hawaii has one hot-water immersion facility that has recently been certified. The purpose of this study was to make a direct comparison of the effects of these two postharvest treatments on longan quality during storage under simulated commercial conditions.

Materials and Methods

Longan fruit were obtained from a grower in Kurtistown, Hawaii, during a commercial harvest on the island of Hawaii, from Oct. through Nov. 2000, and stored in the laboratory in perforated plastic bags in fiberboard boxes at 25 ± 1 °C. One day after harvest, undamaged fruit were randomized for treatments, and baseline quality analyses (described below) were performed on fruit samples before initiation of quarantine treatments. That day, fruit were treated with one of two quarantine treatments: hot-water immersion (HWI) or irradiation (IRR), or left untreated as controls. A factorial experiment consisting of three treatments (control, irradiation, hot-water immersion) × three storage intervals (7, 14, 21 d) was used for each of two longan cultivars (‘Chompoo’, ‘Biew Kiew’) independently. The two cultivars were harvested ripe on the tree on three successive weeks, and each harvest date constituted a replicate.

Hot-water immersion treatment. Tests were conducted at the USDA Agricultural Research Service (ARS) laboratory in Hilo using a 70-L circulating bath heated by two electric heaters (PolyScience immersion circulator model 73) to a constant 49 ± 0.2 °C. This hot-water immersion tank was specifically designed for postharvest research on fresh tropical commodities. The bath temperature was verified before and after each run using a mercury thermometer with 0.1 °C gradations. For HWI treatment, 2.3 kg of fruit were placed in a nylon mesh bag and immersed in water at 49 °C for 20 min. After heating, fruit were immediately placed into a 70-L ambient (≈21 °C) water bath to cool for an additional 20 min. A typical HWI temperature profile is shown in Fig. 1. Fruit were then air-dried in shade for ≈1.5 h before repacking in perforated plastic bags and fiberboard boxes for storage at 10 °C.

Irradiation treatment. For treatment with irradiation, 4.5 kg of fruit in a perforated bag inside a fiberboard box were treated at a nearby commercial X-ray facility (Hawaii Pride, Keaau, Hawaii) using an electron linear accelerator (5 MeV, model TB-5/15; SureBeam Corp., San Diego). Dosimeters (Opti-chromic detectors, FWT-70-83M; Far West Technology, Goleta, Calif.) were placed at six locations inside and two locations outside each box. The dosimeters were read with a FWT-200 reader (Far West Technology) at 600-nm absorbance to verify the minimum absorbed dose and dose variation in each replicate. After irradiation treatment, fruit were repacked in perforated plastic bags and fiberboard boxes

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for storage at 10 °C. Over the course of the study, calculated doses for 'Chompoo' fruit (dosimeters inside boxes only) ranged from an average minimum of 417 Gy to an average maximum of 560 Gy, for a dose uniformity ratio of 1.34; calculated doses for 'Biew Kiew' fruit ranged from an average minimum of 458 Gy to an average maximum of 665 Gy, for a dose uniformity ratio of 1.45.

Quality determination. Fruit quality determinations were performed before treatment and 7, 14, and 21 d after treatment (equivalent to 1, 8, 15, and 22 d after harvest, respectively) and placement in storage at 10 °C with relative humidity at 80%. Quality evaluations included colorimeter measurements, °Brix, pH, total acidity, and heuristic taste comparisons, including ratings by experienced graders and a separate sensory panel. Fifty-four fruit were evaluated per replicate on the day of fruit arrival (1 d after harvest), and 54 fruit/replicate were evaluated for each treatment at the three storage intervals. Quantitative measurements of the external color of the pericarp were made using a Minolta Chroma Meter (Minolta Corp., Ramsey, N.J.), calibrated to a standard white reflective plate and recording in the L*C*h° color system (Lightness, Chroma, and hue angle, respectively). Measurements were taken across an area 8 mm² with diffuse illumination at a viewing angle of 0° under Commission Internationale de l'Eclairage (CIE) illuminant C conditions (McGuire, 1992, 1998). Color values of 30 fruit per treatment were recorded at two equidistant locations around the equator and one at the distal end for each fruit and averaged (first for each fruit, then across all fruit in a treatment). Fifteen of the 54 fruit were then used for chemical analysis. The juice of each fruit was extracted individually by pressing the pulp through a garlic press with 1-mm-diameter openings, and °Brix was directly measured using two or three drops of juice placed on a handheld refractometer (Atago ATC-1E; Daigger & Co., Inc., Lincolnshire, Ill.). The pH of the juice of each fruit was then measured, after which a 1-mL aliquot was diluted with 10 mL of distilled water and titrated to an endpoint of pH 8.1 using 0.0087 N NaOH; percent acidity was based on meq citric acid.

Of the remaining 39 fruit, 15 were used for quality ratings and taste evaluations by three experienced graders. External appearance ratings were based on the degree of darkening of the pericarp: 1 = (best rating) green to light-brown and not darkened, 2 = loss of green, but without darkening, 3 = ≤ 50% surface area darkened, 4 = > 50% surface area distinctly darkened, 5 = (worst rating) 100% darkened outer pericarp. Formal grades and standards have not been developed for longan in Hawaii, but an external appearance rating of 3 or higher would probably indicate reduced commercial acceptability. The presence or absence of *Penicillium* mold also was recorded by graders.

Pericarp texture was evaluated as fruit were hand-peeled. The scale for pericarp texture was 1 = pliable, 2 = tough and leathery, and 3 = brittle. The fruit pulp was rated for its tactile

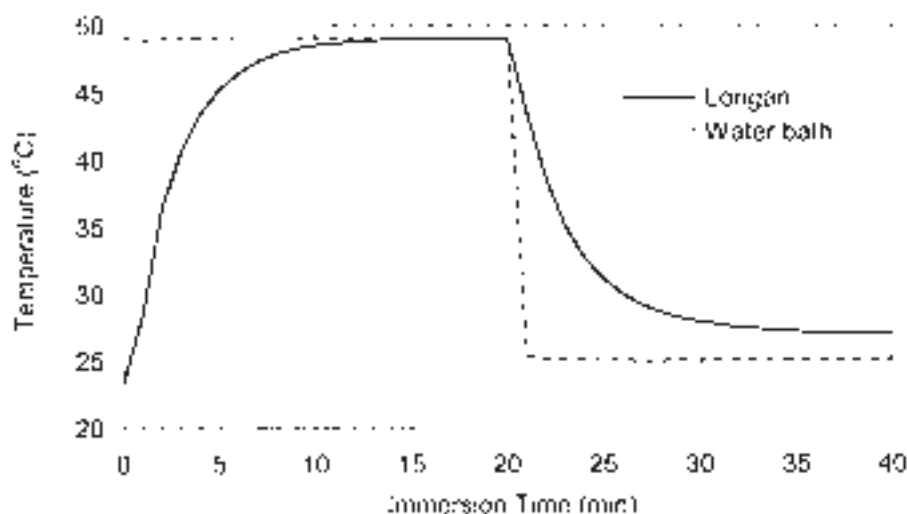


Fig. 1. Temperature profile for longan fruit subjected to hot-water immersion and subsequent cooling in an ambient temperature bath. Temperature measured at the seed surface inside fruit.

Table 1. Physical and chemical qualities of 'Chompoo' longan fruit at various intervals after treatment with hot-water immersion (HWI) or irradiation (IRR).

Days after trmt ^a	Trmt	Pericarp color			Wt loss (%)	°Brix	pH	Acidity (%)
		L*	C*	h°				
Initial		51.2	33.8	88.3	---	20.0	6.5	0.12
7	Control	49.5 a ^y	32.7 a	85.2 a	2.5	21.5	6.8	0.07
	HWI	44.5 a	26.9 a	77.5 a	3.0	21.2	7.0	0.07
	IRR	46.0 a	28.3 a	79.8 a	2.5	21.3	6.8	0.08
14	Control	48.6 a	31.6 a	82.8 a	5.1	21.5	6.8	0.07
	HWI	42.4 b	24.2 b	74.2 b	6.0	21.2	7.1	0.05
	IRR	46.6 a	29.1 ab	79.4 ab	5.9	21.0	6.9	0.06
21	Control	46.7 a	29.6 a	80.8 a	8.4	21.6	6.9	0.06
	HWI	40.9 b	17.9 b	70.0 b	8.6	20.2	6.9	0.06
	IRR	45.5 ab	27.7 a	76.9 a	8.5	21.2	6.9	0.06
Main effects and interaction								
Day		*	*	*	*	NS	NS	NS
Trmt		*	*	*	NS	NS	NS	NS
Day × trmt		NS	NS	NS	NS	NS	NS	NS

^aTemperature of fruit storage for the duration of the experiment was 10 °C; values are means of three replicates.

^yMean separation within columns (by days) by Tukey–Kramer HSD ($P \leq 0.05$).

NS, Nonsignificant or significant at $P \leq 0.05$.

Table 2. Physical and chemical qualities of 'Biew Kiew' longan fruit at various intervals after treatment with hot-water immersion (HWI) or irradiation (IRR).

Days after trmt ^a	Trmt	Pericarp color			Wt loss (%)	°Brix	pH	Acidity (%)
		L*	C*	h°				
Initial		46.5	30.6	83.9	---	20.5	6.4	0.08
7	Control	45.0 a ^y	29.2 a	81.4	3.1	20.3	6.4	0.06
	HWI	44.4 a	28.3 a	79.7	3.1	20.1	6.6	0.05
	IRR	44.8 a	28.4 a	80.2	3.4	20.8	6.5	0.05
14	Control	45.1 a	28.3 a	80.1	5.5	20.5	6.4	0.06
	HWI	41.8 b	23.3 a	73.9	6.4	20.0	6.6	0.05
	IRR	45.5 a	27.9 a	78.3	5.6	20.5	6.5	0.06
21	Control	44.4 a	27.5 a	78.5	8.1	20.2	6.4	0.07
	HWI	43.6 a	15.3 b	74.5	10.1	19.1	6.9	0.06
	IRR	44.4 a	25.7 a	75.2	8.8	19.9	6.9	0.08
Main effects and interaction								
Day		NS	*	*	*	NS	NS	*
Trmt		*	*	NS	NS	NS	NS	NS
Day × trmt		NS	*	NS	NS	NS	NS	NS

^aTemperature of fruit storage for the duration of the experiment was 10 °C; values are means of three replicates.

^yMean separation within columns (by days) by Tukey–Kramer HSD ($P \leq 0.05$).

NS, Nonsignificant or significant at $P \leq 0.05$.

and masticatory properties as 1 = crisp and crunchy, 2 = soft, and 3 = other, which included tissue being watery or slimy or having darkened areas. The scale for taste ratings was 1 = excellent, 2 = acceptable, 3 = off-flavors, 4 = highly distasteful, 5 = choose not to taste.

The final 24 fruit were evaluated by a sensory panel consisting of eight co-workers. Training was provided at the beginning of the study using freshly harvested, best-quality longan fruit of each cultivar as the comparative standard for future judging. Panelists were asked to evaluate three fruit per treatment at the three storage intervals. Fruit presented to panelists had been randomly selected, and the position of each treatment from left to right in front of the panelist was randomized in a “blind test” (Lawless and Heymann, 1998). Evaluation categories included external quality (pericarp color, disease, marketability, and peeling texture), internal quality [pulp color, texture (tactile), wateriness], and taste (texture, flavor, sweetness, tartness). For each attribute, panelists were asked to place a mark on a line that was 13 cm long indicating fruit quality relative to freshly harvested fruit (the standard). The right end was labeled “equals standard,” and the left end was labeled “extremely substandard,” with a reference mark provided at the midpoint of the line. Fruit were served at room temperature. An additional 10 fruit per treatment per replicate of each cultivar were held in storage at 10 °C in perforated plastic bags and fiberboard boxes and weighed 7, 14, and 21 d posttreatment to measure weight loss.

Data analysis. A two-way analysis of variance (ANOVA) procedure using the standard least squares model was used to test for differences in treatment, storage time, and the treatment × storage time interaction for each cultivar independently (SAS Institute, 1997). When the effect of quarantine treatment was significant, a means separation was done using the Tukey–Kramer HSD test at $P \leq 0.05$.

Results

Significant quality differences between quarantine treatments were observed in both cultivars. Treatment effects were significant for L^* , C^* , and h^* for ‘Chompoo’ fruit (Table 1). At 7, 14, and 21 d posttreatment HWI fruit had the lowest L^* , C^* , and h^* values. After 14 d HWI fruit were significantly darker (lower L^*) than IRR or untreated fruit, and after 21 d HWI fruit were significantly less intensely colored (lower C^*) and less yellow-green (lower h^*) than IRR or untreated fruit. Treatment effects were also significant for L^* and C^* for ‘Biew Kiew’ fruit (Table 2). At 7, 14, and 21 d posttreatment HWI fruit had the lowest L^* and C^* values. After 14 d posttreatment HWI fruit were significantly darker (lower L^*) than IRR or untreated fruit, and after 21 d HWI fruit were less intensely colored (lower C^*) than IRR or untreated fruit. Although weight loss in storage increased for both cultivars each sampling day, neither treatment exacerbated the loss compared with that from untreated fruit. There were no significant dif-

Table 3. Sensory qualities of ‘Chompoo’ longan fruit at various intervals after treatment with hot-water immersion (HWI) or irradiation (IRR) and storage at 10 °C.

Days after trmt ^z	Trmt	Experienced graders					Sensory panel		
		Extl. appr. ^y	Pericarp texture ^x	Mold ^w	Pulp ^v	Taste ^u	Extl. appr. ¹	Pulp ⁱ	Taste ⁱ
Initial		1.0	1.0	0.00	1.0	1.0	11.1	11.9	11.9
7	Control	1.2 a ^s	1.2	0.00 a	1.2 a	1.2 a	10.3 a	10.9 a	11.2 a
	HWI	1.7 a	1.6	0.00 a	1.3 a	1.7 a	7.9 b	9.5 b	10.0 b
	IRR	1.7 a	1.5	0.00 a	1.3 a	1.3 a	8.6 b	10.6 ab	10.4 ab
14	Control	1.8 a	1.9	0.01 a	1.5 a	1.2 a	10.0 a	10.7 a	10.9 a
	HWI	2.9 b	2.2	0.01 a	1.5 a	2.0 a	6.6 a	9.4 a	9.0 a
	IRR	2.2 a	2.0	0.00 a	1.4 a	1.6 a	8.7 a	9.9 a	10.3 a
21	Control	2.6 a	2.1	0.03 a	1.8 a	2.0 a	8.3 a	8.7 a	8.9 a
	HWI	4.9 b	2.8	0.98 b	2.8 b	4.9 b	2.1 b	2.5 b	0.9 b
	IRR	2.6 a	2.5	0.05 a	1.8 a	2.0 a	8.0 a	8.2 a	8.4 a
Main effects and interaction									
Day		*	*	*	*	*	*	*	*
Trmt		*	NS	*	*	*	*	*	*
Day × trmt		*	NS	*	*	*	*	*	*

^zTemperature of fruit storage for the duration of the experiment was 10 °C; values are means of three replicates.

^yExtl. appr. = external appearance. 1 = (Best) green to light brown and not darkened; 2 = loss of green; 3 = ≤ 50% surface area darkened; 4 = ≥ 50% surface area darkened; 5 = (worst) 100% darkened outer pericarp.

^x1 = Pliable; 2 = tough and leathery; 3 = brittle.

^wProportion of fruit with *Penicillium* mold.

^v1 = Crisp and crunchy; 2 = soft; 3 = other (watery, darkened areas, slimy).

^u1 = Excellent; 2 = acceptable; 3 = off flavors; 4 = highly distasteful; 5 = choose not to taste.

¹Average distance (cm) from left end of a 13-cm line where the left end was labeled “extremely substandard” and the right end was labeled “equals standard.”

ⁱMean separation within columns (by day) by Tukey–Kramer HSD ($P \leq 0.05$).

^{ns}, *Nonsignificant or significant at $P \leq 0.05$.

Table 4. Sensory qualities of ‘Biew Kiew’ longan fruit at various intervals after treatment with hot-water immersion (HWI) or irradiation (IRR) and storage at 10 °C.

Days after trmt ^z	Trmt	Experienced graders					Sensory panel		
		Extl. appr. ^y	Pericarp texture ^x	Mold ^w	Pulp ^v	Taste ^u	Extl. appr. ¹	Pulp ⁱ	Taste ⁱ
Initial		1.1	1.0	0.00	1.1	1.0	11.7	11.9	12.0
7	Control	1.4 a ^s	1.3	0.00 a	1.2 a	1.3 a	10.9 a	11.0 a	11.5 a
	HWI	1.8 a	1.4	0.00 a	1.2 a	1.7 a	10.8 a	11.1 a	11.5 a
	IRR	1.9 a	1.4	0.00 a	1.2 a	1.3 a	10.8 a	11.6 a	11.7 a
14	Control	1.8 a	1.7	0.01 a	1.3 a	1.6 a	10.2 a	10.1 a	10.9 a
	HWI	3.1 a	2.3	0.22 a	1.6 a	2.4 a	6.7 b	8.0 b	7.4 a
	IRR	2.1 a	1.8	0.01 a	1.3 a	1.5 a	9.8 a	10.2 a	11.0 a
21	Control	2.1 a	2.2	0.00 a	1.3 a	1.5 a	8.5 a	9.3 a	9.4 a
	HWI	5.0 c	2.5	1.00 b	2.4 b	4.6 b	1.0 b	2.4 b	0.6 b
	IRR	2.4 b	2.2	0.01 a	1.4 a	1.8 a	8.3 a	9.1 a	9.2 a
Main effects and interaction									
Day		*	*	*	*	*	*	*	*
Trmt		*	NS	*	*	*	*	*	*
Day × trmt		*	NS	*	*	*	*	*	*

^zTemperature of fruit storage for the duration of the experiment was 10 °C; values are means of three replicates.

^yExtl. appr. = external appearance. 1 = (best) green to light brown and not darkened; 2 = loss of green; 3 = ≤ 50% surface area darkened; 4 = ≥ 50% surface area darkened; 5 = (worst) 100% darkened outer pericarp.

^x1 = Pliable; 2 = tough and leathery; 3 = brittle.

^wProportion of fruit with *Penicillium* mold.

^v1 = Crisp and crunchy; 2 = soft; 3 = other (watery, darkened areas, slimy).

^u1 = Excellent; 2 = acceptable; 3 = off flavors; 4 = highly distasteful; 5 = choose not to taste.

¹Average distance (cm) from left end of a 13-cm line where the left end was labeled “extremely substandard” and the right end was labeled “equals standard.”

ⁱMean separation within columns (by day) by Tukey–Kramer HSD ($P \leq 0.05$).

^{ns}, *Nonsignificant or significant at $P \leq 0.05$.

ferences in °Brix, pH, or acidity for either cultivar due to treatment or storage period.

Treatment effects were significant for both cultivars for all the sensory qualities except texture evaluated by the experienced graders and sensory panel. After 21 d of storage, ‘Chompoo’ fruit treated by HWI were rated as significantly less acceptable than those treated

by IRR or left untreated for external appearance, pulp quality, and taste by both the experienced graders and sensory panel (Table 3). After 14 and 21 d of storage, ‘Biew Kiew’ fruit treated by HWI were rated as significantly less acceptable than those treated by IRR or left untreated for external appearance and pulp quality by the sensory panel (Table 4). After

21 d of storage these fruit treated by HWI were rated as significantly less acceptable than those treated by IRR or left untreated for external appearance, pulp quality, and taste by both the experienced graders and sensory panel. The external appearance of HWI-treated fruit of both cultivars was rated as unacceptable after 14 and 21 d of storage (Tables 3, 4). *Penicillium* mold contributed to the unacceptable external appearance ratings after 21 d in fruit that were treated with hot-water immersion.

Discussion

The two quarantine treatments compared in our study were developed to kill Hawaii's fruit fly pests prior to export of fruit, and treatment protocols are either approved (IRR) or soon to be approved (HWI) for exporting longan. A previous study reported that loss of quality in longan treated with irradiation up to 300 Gy was minimal after 6 d of storage at 5.0 °C (McGuire, 1998). The protocol for the hot-water immersion treatment for lychee (USDA-APHIS-PPQ, 1998) contains warnings about the limited research on fruit quality after treatment application and varying tolerance among different cultivars. Until now, no information was available on the effects of hot-water immersion treatment on longan quality.

After 21 d of posttreatment storage at 10 °C nearly all HWI fruit had surface mold, whereas mold was rare in the IRR and untreated fruit. In an unreplicated follow-up test, the effect of hydrocooling temperature and storage temperature on the external appearance of fruit

were examined; storage at 4.4 °C after HWI of 49 °C for 20 min and hydrocooling at either 23.0 °C (ambient) or 1.0 °C (ice water) for 20 min eliminated the incidence of mold during 14 d of storage (Follett and Sanxter, unpublished). Storage of longan at colder temperatures (1.1 to 5.0 °C) is standard elsewhere (McGregor, 1989; McGuire, 1998; Paull and Chen, 1987); however, cold storage at 1.1 °C can produce severe surface injury to the pericarp (McGuire, 1998). Although growers in Hawaii often store and ship longan at 10 °C, colder storage is indicated, particularly for fruit receiving a hot-water immersion quarantine treatment.

For both 'Chompoo' and 'Biew Kiew' longans, external appearance of fruit treated with hot-water immersion was rated as unacceptable after 14 and 21 d of posttreatment storage, whereas irradiated and nontreated fruit were rated as acceptable on all days. For both cultivars, taste of fruit in all treatments was acceptable after 14 d of storage, but the taste of fruit treated with hot-water immersion was rated as unacceptable after 21 d of storage, whereas irradiated fruit remained acceptable. Therefore, under our conditions, irradiation was superior to hot-water immersion as a quarantine treatment based on maintenance of fruit quality. However, hot-water immersion should be an acceptable treatment when coupled with cold storage at 2 to 5 °C rather than 10 °C. Other market factors in Hawaii, such as the availability of treatment facilities on different islands and costs, will ultimately contribute to the choice of a quarantine treatment.

Literature Cited

- Federal Register. 1997. Papaya, carambola, and litchi from Hawaii. Rules and regulations 62(132):36967-36976.
- Federal Register. 1998. Fruit from Hawaii. Rules and regulations 63(229):65645-65649.
- Follett, P.A. and S.S. Sanxter. 2000. Comparison of rambutan quality after hot forced-air and irradiation quarantine treatments. *HortScience* 35:1315-1318.
- Lawless, H.T. and H. Heymann. 1999. Sensory evaluation of food. Aspen Publ., Gaithersburg, Md.
- McGregor, B.M. 1989. Tropical products transport handbook. U.S. Dept. Agr. Hdbk. 688.
- McGuire, R.G. 1992. Reporting of objective color measurements. *HortScience* 27:1254-1255.
- McGuire, R.G. 1998. The response of longan fruit to cold and gamma irradiation treatments for quarantine eradication of exotic pests. *J. Hort. Sci. & Biotechnol.* 75:687-690.
- Morton, J.F. 1987. Fruits of warm climates. Publ. by Julia F. Morton, Miami, Fla.
- Nakasone, H.Y. and R.E. Paull. 1998. Tropical fruits. CAB Intl., Wallingford, U.K.
- Paull, R.E. and N.J. Chen. 1987. Changes in longan and rambutan during postharvest storage. *HortScience* 22:1303-1304.
- SAS Institute. 1997. JMP user's guide. SAS Inst., Cary, N.C.
- USDA-APHIS-PPQ. 1998. Treatment manual: Interim edition. U.S. Dept. Agr., Riverdale, Md.
- Watson, B.J. 1984. Longan, p. 192-197. In: P.E. Page (ed.). Tropical tree fruits for Australia. Queensland Dept. of Primary Ind., Brisbane.
- Zee, F.T.P., H.T. Chan, and C.-R. Yen. 1998. Lychee, longan, rambutan and pulasan, p. 290-335. In: P.E. Shaw, H.T. Shaw, and S. Nagy (eds.). Tropical and subtropical fruits. Agscience, Inc., Auburndale, Fla.